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INTRODUCTION

It was but twenty short years ago that United States scientists and engineers first employed the sounding rocket to make exploratory measurements in the upper atmosphere and ionosphere, using the V-2 rocket launched from what is now the White Sands Missile Range. It was but ten short years ago that the Soviets launched the first orbiting artificial earth satellite. It was but five short years ago that a Jet Propulsion Laboratory team succeeded in guiding Mariner-2 past our sister planet, Venus. Now in 1967, we have in hand the capability and the opportunity to plan and carry through the unmanned exploration of the major planets and the galactic space which lies beyond the solar magnetosphere. In as little as five years, we may be able to fly by the planet Jupiter, and then escape the gravitational dominance of the sun itself.

SCIENTIFIC GOALS

In our space science program, we seek to understand the origin of the solar system, its evolution, and its present status. By means of deep space probes to the far reaches of the solar system, we can achieve a much better understanding of the sun itself, the propagation of solar radiation and particles, and the interaction of these particles and their associated magnetic fields with the planets and with the galactic medium. We also seek to probe directly that volume of space beyond solar control, and thus come to understand galactic phenomena from first-hand experience. One of the best accounts of the state of our knowledge of solar and cosmic particles and fields has been given by Professor Eugene N. Parker of the University of Chicago. I should like to quote from his note entitled "Scientific Background for a Galactic Probe".

"Observations from earth, together with the theoretical properties of gases and magnetic fields, have supplied a <u>qualitative</u> picture of conditions throughout interplanetary space. The fields and particles in interplanetary space form a dynamical system which is powered principally by coronal expansion at the sun and which extends probably for 10 or more AU beyond the orbit of Earth. The dynamical system consists of the solar wind (the expanding solar corona) and the solar magnetic lines of force which the corona carry out through space. Arrayed around outside against this outward moving system is the interstellar medium composed of gas, magnetic field, and cosmic rays. The interstellar gas and fields are pushed out of the inner solar system completely by the solar wind and its fields. A partial vacuum is produced in the cosmic rays throughout the inner solar system. At the present time the solar wind and its magnetic fields are being monitored and explored at the orbit of Earth, supplying quantitative information on the strengths and intensities of the particles and fields in the general picture. Data is presently available on the solar wind and its fields, and on cosmic ray particles for the past few years of minimum solar activity. Indirect cosmic ray and energetic solar particle information is available over the past ten or twenty years.

"Unfortunately it is not possible to extrapolate the observations of Earth to deduce conditions much beyond the orbit of Earth, with the result that there are a number of important quantitative questions which cannot be answered at the present time. The two ultimate questions are the distance which the solar wind extends outward from the sun and the cosmic ray intensity in interstellar space. As mentioned above, Earth resides in a partial cosmic ray vacuum as a consequence of the outward motion of the magnetic fields in the solar wind. By how much would the cosmic ray intensity rise if the solar wind and its fields fell to a much lower level than at present? Observations from Mariner II suggested a cosmic ray gradient of the order of ten percent per Astronomical Unit. The interplanetary fields observed more recently from Interplanetary Monitoring Platform contain irregularities of such a scale as to suggest, on theoretical grounds, a similar figure. Theoretical estimates suggest that the solar wind extends ten to one thousand Astronomical Units beyond Earth, so that the cosmic ray intensity surrounding the solar system in interstellar space may easily be two or more times higher than here at Earth. Considerations involving the observed dynamical state of the galaxy suggest only that cosmic rays above one billion electron volts per nucleon are not ten times as numerous as here, else their pressure would burst the galaxy.

"A question related to the cosmic ray intensity in interstellar space is the abundance of relativistic electrons. The electrons are observed in the solar system, but their intensity outside is unknown again because of the solar wind. The electrons in interstellar space are responsible, it is believed, for the background nonthermal galactic radio emission, and are intimately connected with the orgin and life of the cosmic rays in the galaxy.

"The partial vacuum of cosmic rays and electrons in the solar system is produced principally by the irregularities in the magnetic field in the solar win beyond Earth. It is necessary to have measurements of both the wind and field densities, as well as their irregularities, for many AU beyond the orbit of Eart to have a picture of the production of the partial vacuum. A measurement of th cosmic ray intensity outward from the orbit of Earth would allow certain statistical properties of the wind and fields to be inferred, but direct measurements of the wind and field would be necessary to check the inferences and give a clear picture of conditions.

"There are other problems, too, which need observation of the interplanetary particles and fields. The dynamical properties of the blast waves and turbulent regions in the wind can be obtained only if their development beyond Earth can be followed for several AU. The production of radiation belts around Jupiter, in a manner analogous to the formation of the terrestial radiation belts, presumably depends upon the density and state of irregularity of the solar wind at five Astronomical Units from the sun. The outward propagation of energetic solar particles past Earth is controlled both by the fields between Earth and the sun and by the fields for many AU beyond Earth.

"Altogether, then, it appears that, with the ongoing exploring and monitoring of particles and fields at the orbit of Earth over the sunspot cycle, the next step in the scientific inquiry involves missions to large distances, particularly to many AU beyond the orbit of Earth..."

In addition to the exciting prospects outlined by Professor Parker, we have an excellent opportunity to investigate the largest planet in the solar system. This planet, Jupiter, occupies more than twice the volume of the rest of the planets put together. It is more than three hundred times as massive as the earth, although its density is only about one-fourth that of earth. It orbits the sun with a period of nearly twelve years, at a distance of approximately five Astronomical Units. Thus, there will be an opposition of earth and Jupiter every thirteen months, which is also the interval between launch opportunities for a Galactic Jupiter probe.

Among the most interesting Jovian phenomena observed in the past decade have been the non-thermal radio emissions in the decimetric and decametric wavelength regions. Theories proposed to explain these emissions hypothesize a strong Jovian magnetic field and trapped charged particles, similar to the earth's Van Allen radiation belts. A Jupiter probe could investigate the radio emissions which have been correlated with the passage of Io, one of the Jovian moons, through the Jovian radiation belt. Because of the large mass and low temperature of Jupiter, we expect that the thermal escape of low mass gases is almost totally inhibited. As a result, we would further expect that Jupiter is far more representative of the primordial material from which the planet was formed than is earth from which the light gases do escape. Consequently, a hydrogen to helium abundance ratio greater than ten would be predicted in agreement with cosmic abundances.

However, this does not seem to be the case. The fading of starlight from Sigma Arietis during an occulation by Jupiter indicated an approximate scale height of eight kilometers. This, together with a temperature of about 130 degrees K, derived from microwave and infrared observations, leads to a predicted mean molecular weight of about four for the Jovian atmosphere just above the clouds. This leads Öpik (ref. 6) to suggest an overwhelming abundance of helium rather than hydrogen. Thus this proposed atmosphere requires processes which permit the escape of hydrogen. Clearly, the direct measurement of the helium to hydrogen ratio represents an important measurement in understanding the evolution and structure of the planet.

We assume the existence of a Jovian surface, although all observations to date have been limited to the cloud layer (Figure 1). It should be noted that observed patterns in the cloud structure may be due to surface features. The famous "red spot" is perhaps the most obvious of these. At this time, it is uncertain whether a flyby mission can yield information concerning this surface other than its temperature. There is some evidence inferring that Jupiter has

Figure 1 – Photograph of Jupiter. (Taken with 200 inch Hale Telescope–from Planets and Satellites–edited by G. P. Kuiper and B. M. Middlehurst–Univ. of Chicago Press 1961.)

an internal heat source in addition to the external solar radiation. This source might be nuclear, chemical, gravitational, or rotational in origin. Past observations have been limited to the nine to thirteen micron infrared spectral region and the one centimeter microwave region, and because of the absorption characteristics of ammonia, are limited to Jovian cloud altitudes. The extension of the infrared measurements to longer wavelengths is most important in establishing Jovian surface temperatures. Measurement of the temperatures of the sunlit and dark side of the giant planet requires a flyby mission and the spatial resolution achieved with a near approach is very important. The identification of an internal heat source and measurements of the detailed characteristics of the magnetic field could yield significant information about the interior of Jupiter.

Accurate tracking of the spacecraft throughout its long flight before, during, and after its encounter with Jupiter, should improve the accuracy of at least two astronomical constants, i.e., the Astronomical Unit, and the Jovian gravitational constant.

Between the orbits of Mars and Jupiter lies a region known as the asteroid belt. Measurements of the flux of micrometeroids in this belt, as well as in the vicinity of Jupiter, would be most helpful in refining our present gross estimates of the distribution of dust and micrometeoroids in interplanetary space.

It must be apparent that two of the environmental characteristics of interplanetary space between the earth and Jupiter represent possible hazards to the Galactic Jupiter probe. The first of these is the asteroid belt itself, through which the spacecraft must pass in order to reach Jupiter without going to the north or south of the ecliptic plane. The second of these is the trapped radiation belts of Jupiter itself. In both cases, after estimates of the maximum flux that may be encountered have been developed, it will be important to provide safety margins against unexpectedly large densities, and instrumentation to observe the rise of these fluxes long before they can reach levels which may be hazardous to the survival of the spacecraft.

I think it is apparent from even this brief glimpse that the scientific goals of the Galactic Jupiter Probe are both challenging and worthwhile. It is on this basis that the National Aeronautics and Space Administration is making a serious study of the feasibility of carrying out this program. Let me outline our thoughts in this regard.

PROGRAM AND MISSION CONCEPTS

Present thinking involves a spacecraft which could be launched at thirteen-month intervals beginning as early as 1972. Early spacecraft in the series would probably weigh nearly five hundred pounds.

Each mission would involve a flight through the asteroid belt, and a flyby of the planet Jupiter. Beyond this point, at least five separate missions suggest themselves, each using the gravitational assistance of a flyby:

1. The Jovian mass could be used to shape the trajectory away from the sun toward the outer regions of the solar system. Communications would probably limit tracking of the probe to distances up to perhaps ten Astronomical Units.

2. By directing the incoming trajectory of the spacecraft near a pole of the planet, the spacecraft's departure trajectory over the opposite hemisphere of the planet could be directed along any desired angle (e.g., forty-five degrees) out of the ecliptic plane and over the sun.

3. Jupiter could also be used as a means of negating the probe's angular velocity around the sun so that the probe falls radially from its encounter with Jupiter into the sun.

4. The years 1977 and 1978 are being discussed as suitable launch dates for a "Grand Tour" visit to Saturn, Uranus, and Neptune — again using Jupiter assistance.

5. When increased payload weight permits, a second generation spacecraft could be put into orbit about Jupiter for a more detailed investigation of its radiation belts, atmosphere, and surface features.

It is obvious that there will be no scarcity of mission proposals, but where does the NASA Galactic Jupiter Probe program stand today? Substantial study effort has gone on during the past several years at the Goddard Space Flight Center, at the Jet Propulsion Laboratory, and at other organizations (references (1) through (5)) to analyze in detail suggested missions using Jupiter gravity assistance. Figure 2 shows Mission 1, in which the probe remains in the plane of the ecliptic, continuously monitors the space environment between here and Jupiter, and makes measurements through the asteroid belt. It samples the Jovian environment as it passes the planet at a distance of about ten Jupiter radii (690,000 Km), and picks up an incremental velocity from Jupiter whose orbital velocity of 13.1 kilometers per second increases significantly the probe's velocity so that it may escape the gravitational control of the sun.

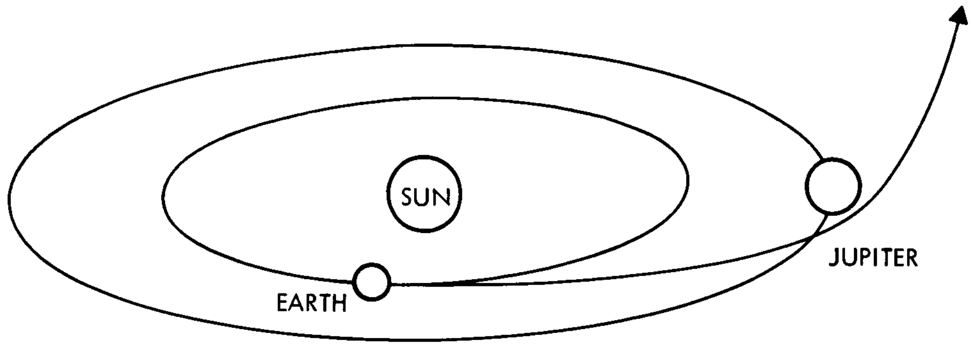

Figure 2 – Deep Space Mission in the Plane of the Ecliptic (Mission 1).

Figure 3 illustrates the Mission 2 concept, for which the probe's trajectory is similar to that of the previous mission, except that the spacecraft is directed over the north or south pole of Jupiter. The departure trajectory can be adjusted to produce inclinations with the ecliptic up to ninety degrees.

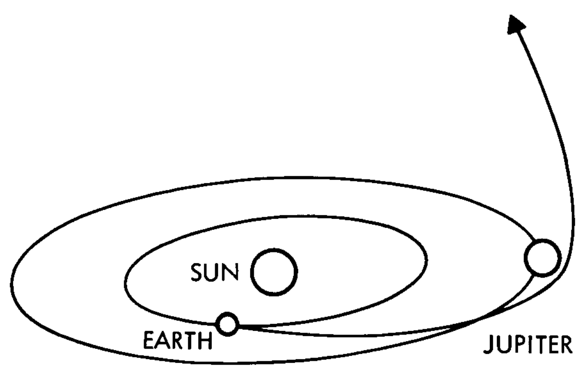

Figure 3 – Out-of-Ecliptic Mission (Mission 2).

In this mission the probe can be made to escape the sun's gravitational control; or it can be put into solar orbit with perihelion between 1/3 and 1 A.U., an excursion north and south of the ecliptic of about 2 A.U. in each direction, and a period typically 4-1/2 to 5 years (ref. 1). A concept of this nature is most attractive, in that it would permit observation for the first time of propagated solar particles and fields from other than the ecliptic plane. In addition, it would be of great importance to obtain data on the distribution of solar system dust and micrometeoroids outside the principal plane of solar system rotation.

Mission 3 is that of a solar probe using Jupiter to cancel the spacecraft's angular velocity about the sun, thus causing the spacecraft to proceed radially from the vicinity of Jupiter to impact the sun. This mission would require, if launched during the 1972 window, about 31-1/2 months of flight time. The radial passage from Jupiter to the sun will require about 16-1/2 months of this time (ref. 1). This mission is particularly attractive due to its sampling of the sun's magnetosphere from five Astronomical Units down to a few solar radii in this comparatively short period of time. In the terminal phase of the mission the probe enters the Solar photosphere traveling in excess of 600 km/sec. It is literally impossible to launch an appreciable payload directly from the earth into the sun with even our largest available launch vehicle of today. This is because of the requirement for an hyperbolic excess velocity of 29.8 kilometers per second when leaving earth orbit, in order to negate the earth's orbital velocity about the sun.

Mission 2 and Mission 3, as described above, require trajectories of somewhat higher energy than Mission 1. It is believed that the launch vehicle under consideration can accomplish Mission 1, but its capability to handle Missions 2 and 3 is problematical, at least for the spacecraft weights under discussion.

A POSSIBLE FIRST MISSION CONFIGURATION

Trajectory

It appears that an initial Galactic Jupiter Probe flight could be scheduled as early as during a twenty day launch window centered on the first week of March in 1972. If we assume a selection of the deep space Mission 1 for our first launch, the trajectory would look like that shown in Figure 4.

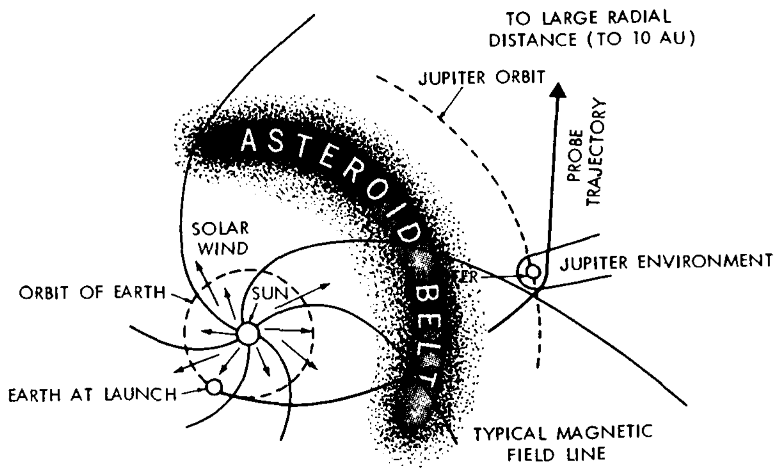

Figure 4 – Galactic Jupiter Probe Trajectory.

The planetary encounter occurs between seventeen and twenty months after launch (Figure 5), and the probe reaches ten Astronomical Units in about three years. This distance would approximate the range limit of the communication system under consideration for the first flight.

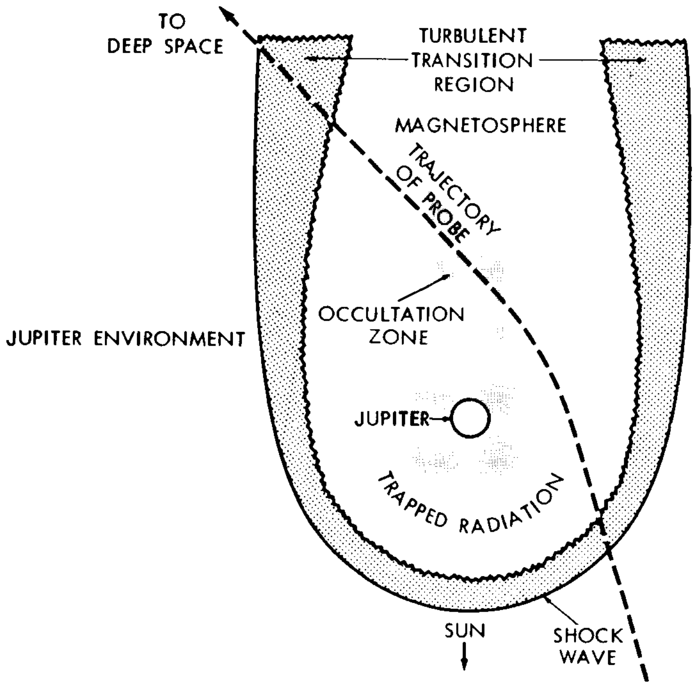

Figure 5 – Jupiter Encounter.

Launch Vehicle

Assuming a spacecraft weight of five hundred pounds, we believe that a vehicle of the Atlas-Centaur class can be adapted to this mission. This requires two engineering developments, neither of which appears to be unrealistic. The first involves improvements to the Atlas to permit it to carry more propellant and consequently more payload. The second involves the utilization of a solid propellant kick stage, such as the proven TE-364 retromotor used on Surveyor.

The Spacecraft

Figure 6 shows one preliminary concept of the Galactic Jupiter Probe spacecraft. Its most prominent features are the eight-foot parabolic communications antenna, the two 25-foot magnetometer and experiment booms, and the radioisotope thermoelectric generators. Electronic subsystems and experiment packages are mounted next to the propellant tanks required for mid-course correction of the trajectory and for attitude control. The circular frame in the center is the mating adapter for the kick stage, which is separated shortly after firing. The spacecraft would be spin-stabilized and earth oriented. Orientation can be achieved by having the spacecraft "home" on an earth emitted RF signal.

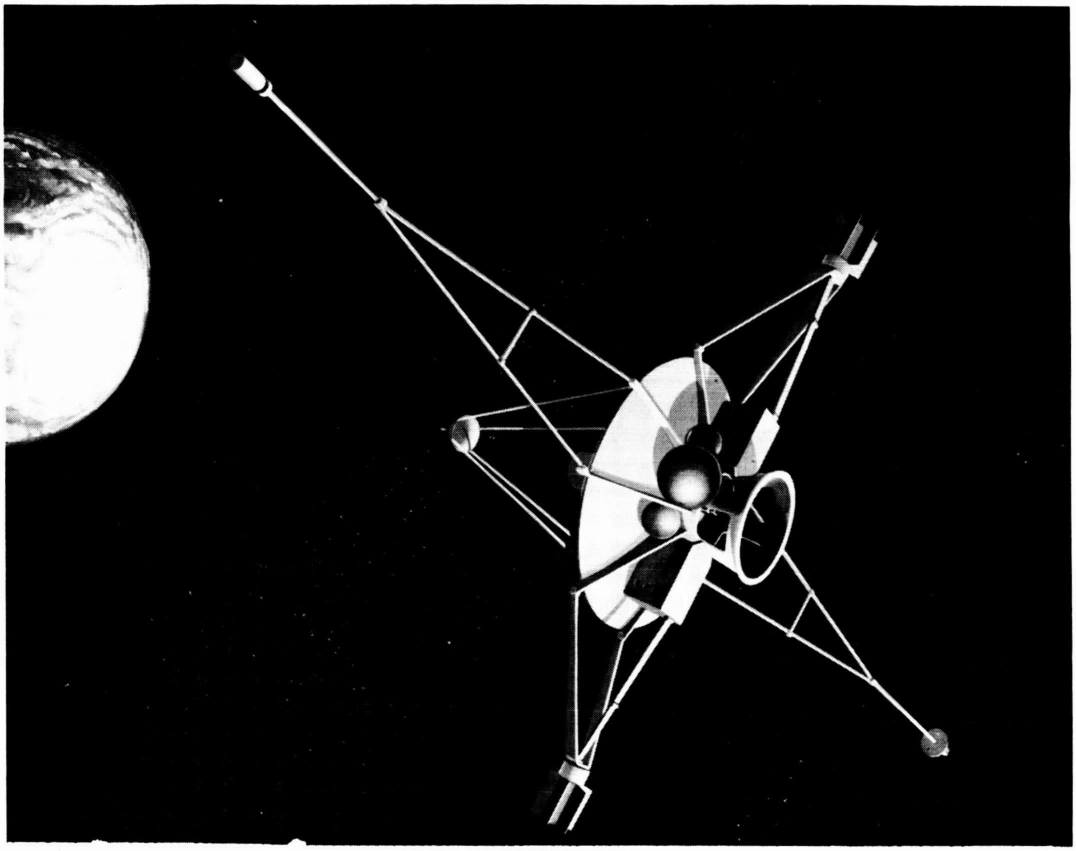

Figure 6 – Artist's Conception of Galactic Jupiter Probe Spacecraft.

A rather novel feature is the use of radioisotope thermoelectric generators (RTGs). The amount of solar energy available at Jupiter's orbit compared to that of earth is decreased by a factor of twenty-five, leaving one very little choice but to use the RTG. Its integration into the spacecraft poses some interesting problems. The RTG produces about twenty thermal watts for each electrical watt, and a radiation environment which must be controlled so as not to interfere with measurement of interplanetary energetic particles.

Scientific Payload

Ultimately, the scientific payload will be made up of the best experiments proposed by prospective principal investigators from the entire scientific community. Since we will be limited to something like forty pounds of scientific instruments per launch, it is apparent that we cannot accommodate enough experiments to investigate all the questions now being posed regarding the interplanetary and Jupiter environment, even in a preliminary and exploratory way. It is also apparent that the payload would be configured differently for the Jupiter flyby optimized for minimum flight time to ten Astronomical Units, corresponding to a distance of closest approach to Jupiter of ten to twelve radii, as contrasted to that of a flyby out of the ecliptic plane where the distance of closest approach might be one to two Jupiter radii above the clouds. Consequently, we are not putting together predetermined payloads. Rather, we are compiling up-to-date information on many possible experiments, determining their constraints on and interaction with the spacecraft, and trying to provide for their requirements within our other constraints. Measurements which can be performed just as well from the vicinity of the earth with balloons, rockets, or satellites are not included for consideration for the Galactic Jupiter Probe payload.

Let us refer again to the spacecraft sketch of Figure 6 to explore some of the accommodations for the scientific payload. The RTG power supplies are mounted on booms for two reasons. One is to achieve the largest possible solid angle for dissipation of RTG heat by radiation. The second is to reduce the irradiation of experiments and spacecraft electronics in the main body area to levels which are compatible with the mission durations to be expected. One of the longer booms would probably contain sensors for the charged particle detectors for galactic cosmic radiation, solar particles, and trapped radiation. Hopefully, the boom length plus a moderate amount of shielding of the boom package can reduce the RTG gamma and neutron fluxes to tolerable levels for the sensors. The other long boom would probably be used to reduce the spacecraft-associated magnetic fields to the very low level required for the magnetometers, both AC and DC. At five AU, we expect the interplanetary field to be approximately one gamma (10^{-5} Oersted), and vector measurements of this field are required. Thus, it will be necessary to reduce the spacecraft-associated field to values of less than 0.1 gamma at the magnetometer.

The earth-pointing side of the hyperbolic sub-reflector will provide for mounting experiments which need pointing to the earth or in the general direction of the sun. For example, a cluster of plasma detectors and the receivers and antenna stubs for a radio propagation experiment would require such pointing.

The main body packages, tightly integrated for thermal control and for micrometeoroid protection, will provide for the majority of the planetary experiments such as infrared and ultraviolet scanners, radio astronomy, and for some interplanetary and planetary experiments, such as the micrometeoroid detectors. The same package will house the majority of the spacecraft and experiment electronic systems also.

Technological Considerations

There are a number of interesting design areas related to this mission. Alternate approaches are being proposed for each of them and it will be necessary to evaluate all and make selections.

The areas which concern us mostly are those in System Reliability, Thermal Design, Meteoroid Protection, RTG created radiation environment, Stored Data, and Communications.

System Reliability — The problem of operating a spacecraft for 3.5 years in a hostile thermal and RTG environment is unique at this time. There are essentially three aspects of reliability which must be resolved:

1. The proper selection of materials and components.
2. An optimum design in terms of redundancy.
3. An assurance of a reasonable value of mission success.

In the selection of materials and components we would hope to draw upon the best available data and techniques relating to radiation resistance, screening and burn-in, and component parameter stability criteria. In the design optimization we would plan a computer study of subsystem configurations to maximize system reliability and minimize weight. And lastly, the question of assessing mission success requires that one give a great deal of thought to the various phases and objectives of the 3.5 year mission and make reasonable judgments of weights to be assigned to each phase and objective. A study of the time accumlative probability of success of the mission should prove useful in implementing system reliability in a manner commensurate with the worth assigned to the different phases and objectives.

Thermal Design — A problem which will require careful attention is the thermal control of the spacecraft. The system design must maintain temperatures of operating equipment within acceptable limits. Structural and mechanical components must be kept free from excessive thermal stress. The design must provide thermal control from Earth orbit to Jupiter and beyond to 10 AU. The spacecraft must reckon with a solar heat input variation of 100 to one. In addition the spacecraft must provide adequate management of the several kilowatts of thermal energy which must be continually radiated and conducted from the RTGs.

Meteoroid Protection — Micrometeoroid protection of the spacecraft will require very careful evaluation. Let us consider the several regions of concern during our Jupiter flyby. There is the near earth environment, the region between Earth and the Asteroids, the region of the Asteroid Belt proper, the Jupiter environment, and the post Jupiter to 10 AU environment.

The near Earth and near interplanetary regions are presumably defined. Models have been postulated for the Asteroid Belt and Jupiter. It is difficult to have much confidence in these models, based as they are on very limited experimental data. However, it may be necessary for design insurance purposes to conjecture a particle flux and density some "X" orders of magnitude greater than that observed in Earth orbit and which is compatible with the most acceptable current model of the Asteroid Belt particle distribution.

It might be noted here that current design of meteoroid shielding leaves much room for improvement because of the present day lack of test facilities for accelerating representative size particles to suitable velocities to permit the check out of shielding designs and materials.

RTG Created Radiation — Still other problems relate to the environment resulting from the RTG generation of neutrons and gamma rays. In most cases the radiation is not immediately fault-inducing to the spacecraft equipment. However, as one examines the integrated fluxes of neutrons over a 3-1/2 year period, it becomes apparent that the dosage must be engineered down to an acceptable level. The judicious placement of equipment, experiments, RTG's a radiation shielding, must be part of the optimized structural layout brought about by the use of RTG's. In addition to the hazard noted here, the problem keeping the RTG radiation "noise" from adversely affecting the experiment radiation detectors is also of paramount importance if one is to perform scie successfully with the spacecraft.

Stored Data — Is it desired to have the spacecraft make scientific measurements continuously throughout the flight? If so, would this require contint ous coverage by ground stations? For most of its trip the spacecraft would be able to acquire data at a fairly low rate commensurate with its changing environment. At other times, especially during Jupiter encounter, it would be de sirable to be able to acquire data on trapped radiation fluxes at a rate higher than expected and faster than it can be transmitted, due to the power and bandwidth limitations of the communications system. How to accommodate these several conflicting requirements will pose something of a design challenge.

Communications — The spacecraft communications system will be "sized" to be compatible with the Satellite Tracking and Data Acquisition Network (STADAN) 85 ft antennas. With an 8 ft parabolic spacecraft antenna and 10 watts of transmitted power, we can expect to maintain spacecraft contact to Jupiter encounter. At this range the data rate will be a minimum, about 10 to 30 bits per second. We would then expect to call upon the Deep Space Network (DSN) 210 ft antennas to provide for increased data rate capability during Jupiter encounter. Thereafter it would be necessary to use the 210 ft antennas to maintain contact with the spacecraft to a limiting range of about 10 AU.

CONCLUSIONS

The Galactic Jupiter Probe program is one which is challenging and timely. We believe its challenge is welcomed with confidence by the scientific and engineering communities alike.

The scientific goals toward which this program are directed are both broad and basic. They are necessary to fill the gap in our knowledge of the solar system beyond the orbit of Mars, particularly at the outermost boundary of the solar magnetosphere as it presses against the galactic medium.

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